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TECHNICAL MEMORANDUM

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PRELIMINARY FULL-SCALE POWER-OFF DRAG OF THE X-15 AIRPLANE FOR MACH NUMBERS FROM 0.7 TO 3.1

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PRELIMINARY FULL-SCALE POWER-OFF DRAG OF THE X-15 AIRPLANE FOR MACH NUMBERS FROM 0.7 TO 3.1*

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SUMMARY

Drag characteristics have been obtained for the X-15 airplane during unpowered flight. These data represent a Mach number range from about 0.7 to 3.1 and a Reynolds number range from 13.9×10^6 to 28×10^6, based on the mean aerodynamic chord.

The full-scale data are compared with estimates compiled from several wind-tunnel facilities. The agreement between wind-tunnel and full-scale supersonic drag, uncorrected for Reynolds number effects, is reasonably close except at low supersonic Mach numbers where the flight values are significantly higher.

INTRODUCTION

Three X-15 airplanes have been constructed for use in hypersonic flight research. To date, two of these airplanes have been flown, powered by interim rocket engines. The flights have consisted, primarily, of maneuvers to investigate low-speed handling qualities, check out the systems, demonstrate structural integrity, and provide pilot familiarization. Although only about one-half of the X-15 design speed and altitude potential has been realized, the performance attained is in excess of the capabilities of any other current airplane.

Little full-scale drag data are available on any airplane at speeds above $M \approx 1.5$. Therefore, since the X-15 data extend to $M \approx 3$, the results of these early flights are considered to be of interest.

*Title, Unclassified.

This paper concerns the drag characteristics of the two airplanes flown thus far, which are considered identical, over the Mach number range from about 0.7 to 3.1. The flight data are compared directly with estimated values which have been compiled by the airplane manufacturer, North American Aviation, Inc., from wind-tunnel tests made at several facilities. Differences in wind-tunnel and full-scale Reynolds numbers are not considered in the comparisons because of a lack of sufficiently accurate full-scale base-pressure data.

It is planned to obtain more accurate and sufficient base-pressure data during future flights to adequately account for base drag. A meaningful study of Reynolds number effects, wind-tunnel to full-scale, will then be attempted.

SYMBOLS

a_l	longitudinal acceleration, g units
a_n	normal acceleration, g units
C_D	drag coefficient, D/qS
ΔC_D	increment in drag coefficient
C_L	lift coefficient, L/qS
$\frac{dC_D}{dC_L^2}$	drag-due-to-lift factor
D	drag force along flight path, lb
g	gravitational acceleration, ft/sec^2
L	lift force normal to flight path, lb
l	length, ft
M	Mach number
p_O	free-stream static pressure, lb/sq ft
q	dynamic pressure, $0.7M^2p_O$
R	free-stream Reynolds number, $\frac{\rho V l}{\mu}$

S	wing area, sq ft
V	true airspeed, ft/sec
W	airplane weight, lb
α	angle of attack, deg
δ_h	mean horizontal-control-surface deflection, $\frac{\delta_{h_{left}} + \delta_{h_{right}}}{2}$, deg
δ_j	speed-brake deflection, deg
μ	absolute viscosity, lb-sec/sq ft
ρ	air density, slugs/cu ft

Subscript:

max	maximum

AIRPLANE

The X-15 is a single-place, low-aspect-ratio monoplane (figs. 1 and 2) designed for aerodynamic research at maximum speeds on the order of 6,600 feet per second. The X-15 is carried to an altitude of about 45,000 feet by a B-52 carrier airplane and launched at a Mach number near 0.8.

When design speed is achieved, the X-15 will be propelled by a single rocket engine providing on the order of 55,000 pounds of thrust under flight conditions. For the flights made to date, however, the airplane has been powered by a cluster of eight XLR11 rocket chambers with a combined thrust of approximately 16,000 pounds under flight conditions. This provides slightly more than 4 minutes of powered flight, after which the airplane glides to a landing on the dry lakebed at Edwards Air Force Base, Calif.

From the standpoint of drag, the most unusual aspect of the X-15 is the large, blunt base, an area of about 31 square feet when the jettisonable lower ventral fin is attached. Another item of interest is the speed-brake configuration and location (fig. 1). The brakes have a total frontal area of 13.8 square feet when they are fully deflected.

Other detailed physical characteristics of the airplane are presented in table I.

INSTRUMENTATION

The X-15 airplane carried standard NASA internal-recording instruments for measuring quantities pertinent to evaluating lift and drag.

Free-stream total and static pressures were sensed from nose-boom stations 71 inches and 63 inches, respectively, ahead of the intersection of the airplane nose and the boom. Angle of attack was measured by a vane located about 43 inches forward of this intersection. Angle of attack has been corrected for the effects of pitching velocity and inertia bending of the nose boom. The accelerometers were located as close to the center of gravity as practical, and corrections were made to compensate for any remaining displacement.

ACCURACY

The following table lists the maximum estimated errors that each of five major error sources could contribute to drag coefficient at a Mach number of 2 and a dynamic pressure of 450 pounds per square foot.

Source of error	Maximum error in source	Resultant error in C_D	
		$\alpha = 0°$	$\alpha = 5°$
a_l, g	0.0005	0.0009	0.0009
a_n, g	.03	0	.0005
α, deg	.5	0	.0017
q, psf	10	.0017	.0022
W, lb	500	.0023	.0019

Because these errors tend to be random, their effect on C_D is not represented by their sum. The preceding table is included only to provide an insight into the relative significance of the various error sources. Based upon examination of the subject data and experience with similar instrumentation systems, it is estimated that the faired values of drag coefficient shown in the summary data (fig. 5) are accurate to ±4 percent for lift coefficients of 0.2 or less.

TEST CONDITIONS

The drag data reported herein represent gliding flight, inasmuch as the rocket-engine-nozzle coefficients had not been obtained through thorough thrust-stand calibrations. The lower ventral was attached throughout these tests, and the airplane was in the clean configuration except where, as noted, the speed brakes were deflected.

As inferred in the INTRODUCTION, to date, the flight maneuvers and instrumentation have not been ideally suited to the determination of drag. A few push-down or pull-up maneuvers were obtained, however, which provide a preliminary view of the X-15 drag characteristics. The tests ranged in Mach number from about 0.7 to about 3.1, providing a free-stream Reynolds number range from 1.35×10^6 to 2.7×10^6 per foot. This corresponds to a Reynolds number range of about 13.9×10^6 to 28×10^6, based on the mean aerodynamic chord. Data recorded from two brief intervals with speed brakes deflected are included.

Center-of-gravity position varied between 20 and 24 percent of the mean aerodynamic chord for these tests. As can be seen in the basic data, mean horizontal-control-surface deflection is indicated for all maneuvers where available so that a more detailed comparison with wind-tunnel data may be made if desired. All flight data in the summary figures represent the horizontal-control-surface deflections shown for the respective Mach numbers and lift coefficients in figure 3. Examination of the flight data has shown that negligible or zero pitching acceleration was experienced for most of the data points used in preparing figures 4 to 7.

PROCEDURES

The accelerometer method was used to determine lift and drag. For power-off conditions the following equations apply:

$$C_L = \left(\frac{Wa_n}{qS}\right) \cos \alpha - \left(\frac{Wa_l}{qS}\right) \sin \alpha$$

$$C_D = \left(\frac{Wa_l}{qS}\right) \cos \alpha + \left(\frac{Wa_n}{qS}\right) \sin \alpha$$

Details regarding this method may be found in reference 1.

DISCUSSION OF RESULTS

Basic Data

The basic data are shown in figures 3(a) to 3(j) in which drag coefficient, horizontal-control-surface deflection, and angle of attack are related to lift coefficient for each test Mach number. Free-stream Reynolds numbers for the tests are indicated for each set of basic data.

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All data represent the clean configuration with power off and the lower ventral on, except for some brief data obtained at subsonic speeds where the speed brakes were deflected (figs. 3(a) and 3(b)). These data indicate a drag-coefficient increase of 0.060 and 0.114 for speed-brake deflections of 23° and 35°, respectively. For the 35°-deflection the drag increases about 115 percent, for a frontal-area increase of about 35 percent, at $C_L \approx 0.35$. The following table compares these data with the estimates of reference 2.

M	C_L	δ_j, deg	$\Delta C_{D_{flight}}$	$\Delta C_{D_{estimated}}$	$\frac{\Delta C_{D_{estimated}}}{\Delta C_{D_{flight}}}$, percent
0.72	0.23 to .33	23	0.060	0.052	86.6
.87	.33 to .40	35	.114	.100	87.7

Summary Figures

Figures 4(a) and 4(b) show a comparison of three typical drag polars with the estimated polars of reference 2. Although the agreement is reasonably good for the lowest and highest Mach numbers, the flight-measured drag is significantly higher for a Mach number of 1.1. An explanation for this disagreement is not offered; however, it has been determined that trim differences can account for only a very small part of this drag increment.

A summary of full-scale drag-coefficient variation with Mach number is shown in figure 5. Estimated values of drag coefficient obtained from reference 2 are included for comparison. As can be seen, the full-scale values of drag coefficient are significantly higher for supersonic Mach numbers below about 1.5, $C_L = 0.1$.

The drag-due-to-lift characteristics of the X-15 airplane are presented in figure 6. As can be seen, the drag due to lift is higher than estimated at the higher supersonic Mach numbers and lower than estimated in the subsonic region. One-third to one-half of the disagreement in drag due to lift, supersonically, is a result of horizontal-control-surface deflections which were higher than those assumed in reference 2.

The resultant lift-drag ratios obtained for power-off flight are shown in figure 7. The lift-coefficient range experienced in flight was not sufficient to acquire maximum lift-drag ratios throughout the Mach number range. It is apparent, however, that the subsonic maximum lift-drag ratio is greater than estimated, because the lower full-scale drag due to lift is the dominant drag factor at the lift coefficient where maximum lift-drag ratio occurs. The supersonic ratios measured are less than estimated, as a result of higher than estimated drag at low lift up to $M \approx 1.5$ and higher than estimated drag due to lift at higher Mach numbers.

CONCLUDING REMARKS

The most significant result of this preliminary survey of the drag of the X-15 research airplane is that the agreement of the wind-tunnel and full-scale supersonic drag, unadjusted for Reynolds number effects, is reasonably close except at Mach numbers between 1.1 and 1.5 where flight measured values are significantly higher.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., November 1, 1960.

REFERENCES

1. Beeler, De E., Bellman, Donald R., and Saltzman, Edwin J.: Flight Techniques for Determining Airplane Drag at High Mach Numbers. NACA TN 3821, 1956.

2. Anon.: Revised Basic Aerodynamic Characteristics of the X-15 Research Airplane. Rep. NA-59-1203 (Contract AF 33(600)-31693), North American Aviation, Inc., Aug. 7, 1959.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE

Wing:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 94.98 sq ft covered by fuselage), sq ft	200
Span, ft	22.36
Mean aerodynamic chord, ft	10.27
Root chord, ft	14.91
Tip chord, ft	2.98
Taper ratio	0.20
Aspect ratio	2.50
Sweep at 25-percent-chord line, deg	25.64
Incidence, deg	0
Dihedral, deg	0
Aerodynamic twist, deg	0
Flap -	
Type	Plain
Area (each), sq ft	8.30
Span (each), ft	4.50
Inboard chord, ft	2.61
Outboard chord, ft	1.08
Deflection, down, deg	40
Ratio flap chord to wing chord	0.22
Ratio total flap area to wing area	0.08
Ratio flap span to wing semispan	0.40
Trailing-edge angle, deg	5.67
Sweepback angle of hinge line, deg	0
Horizontal tail:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 63.29 sq ft covered by fuselage), sq ft	115.34
Span, ft	18.08
Mean aerodynamic chord, ft	7.05
Root chord, ft	10.22
Tip chord, ft	2.11
Taper ratio	0.21
Aspect ratio	2.83
Sweep at 25-percent-chord line, deg	45
Dihedral, deg	-15
Ratio horizontal-tail area to wing area	0.58
Movable surface area, sq ft	51.77
Deflection -	
Longitudinal, up, deg	15
Longitudinal, down, deg	35
Lateral differential (pilot authority), deg	±15
Lateral differential (autopilot authority), deg	±30
Control system	Irreversible hydraulic boost with artificial feel

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE - Concluded

Upper vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	40.91
Span, ft	4.58
Mean aerodynamic chord, ft	8.95
Root chord, ft	10.21
Tip chord, ft	7.56
Taper ratio	0.74
Aspect ratio	0.51
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.20
Movable surface area, sq ft	26.45
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel
Lower vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	34.41
Span, ft	3.83
Mean aerodynamic chord, ft	9.17
Root chord, ft	10.21
Tip chord, ft	8
Taper ratio	0.78
Aspect ratio	0.43
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.17
Movable surface area, sq ft	19.95
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel
Fuselage:	
Length, ft	50.75
Maximum width, ft	7.33
Maximum depth, ft	4.67
Maximum depth over canopy, ft	4.97
Side area (total), sq ft	215.66
Fineness ratio	10.91
Speed brake:	
Area (each), sq ft	5.37
Mean span (each), ft	1.60
Chord (each), ft	3.36
Deflection, deg	35
Frontal area at maximum deflection, sq ft	13.8
Base area (fuselage, side fairings, vertical fins), sq ft	31.18
Total frontal area (maximum) including wing and horizontal tail at 0° deflection, sq ft	38.8

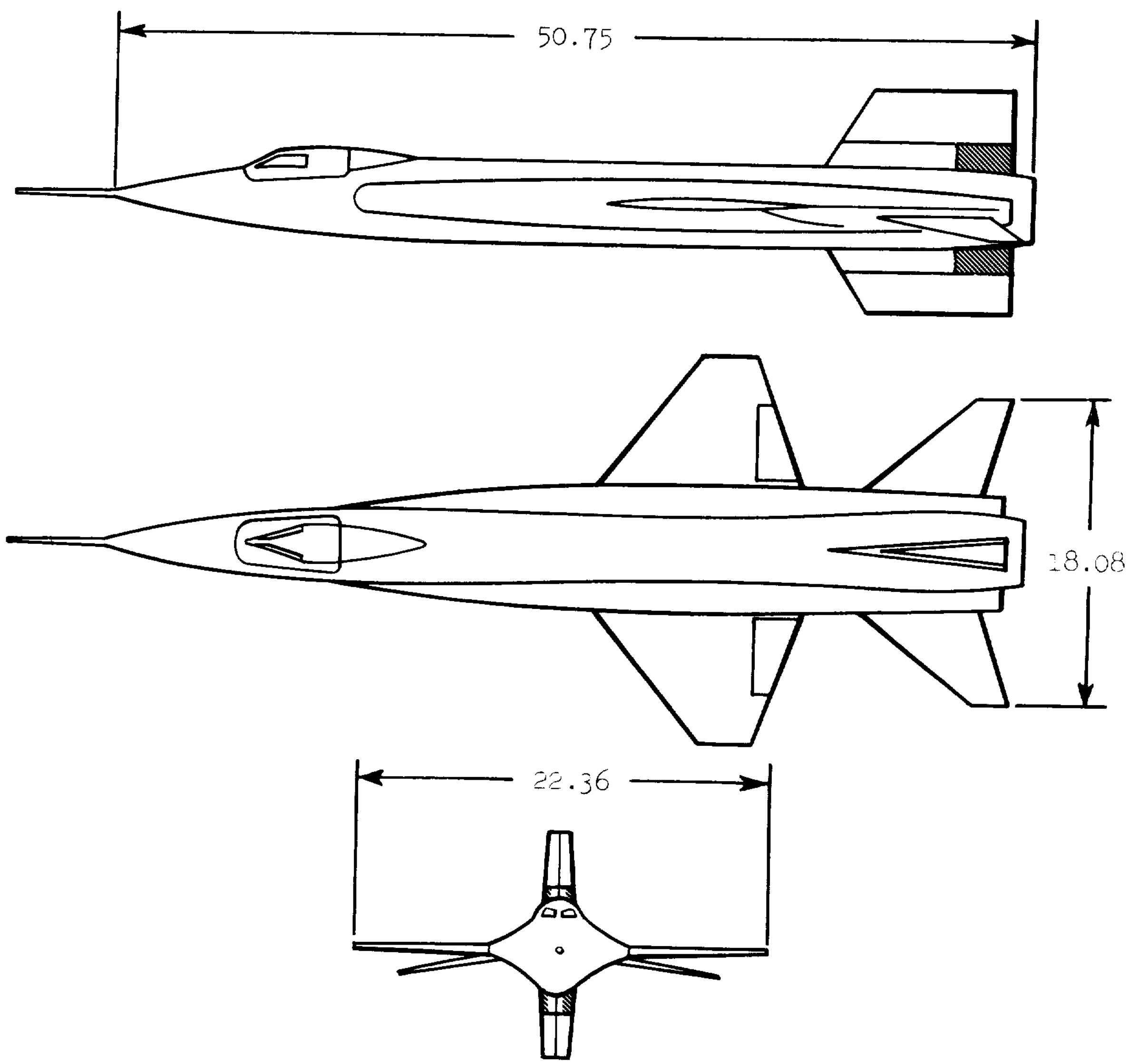


Figure 1.- Three-view drawing of the X-15 airplane. All dimensions in feet. Speed brakes shown crosshatched.

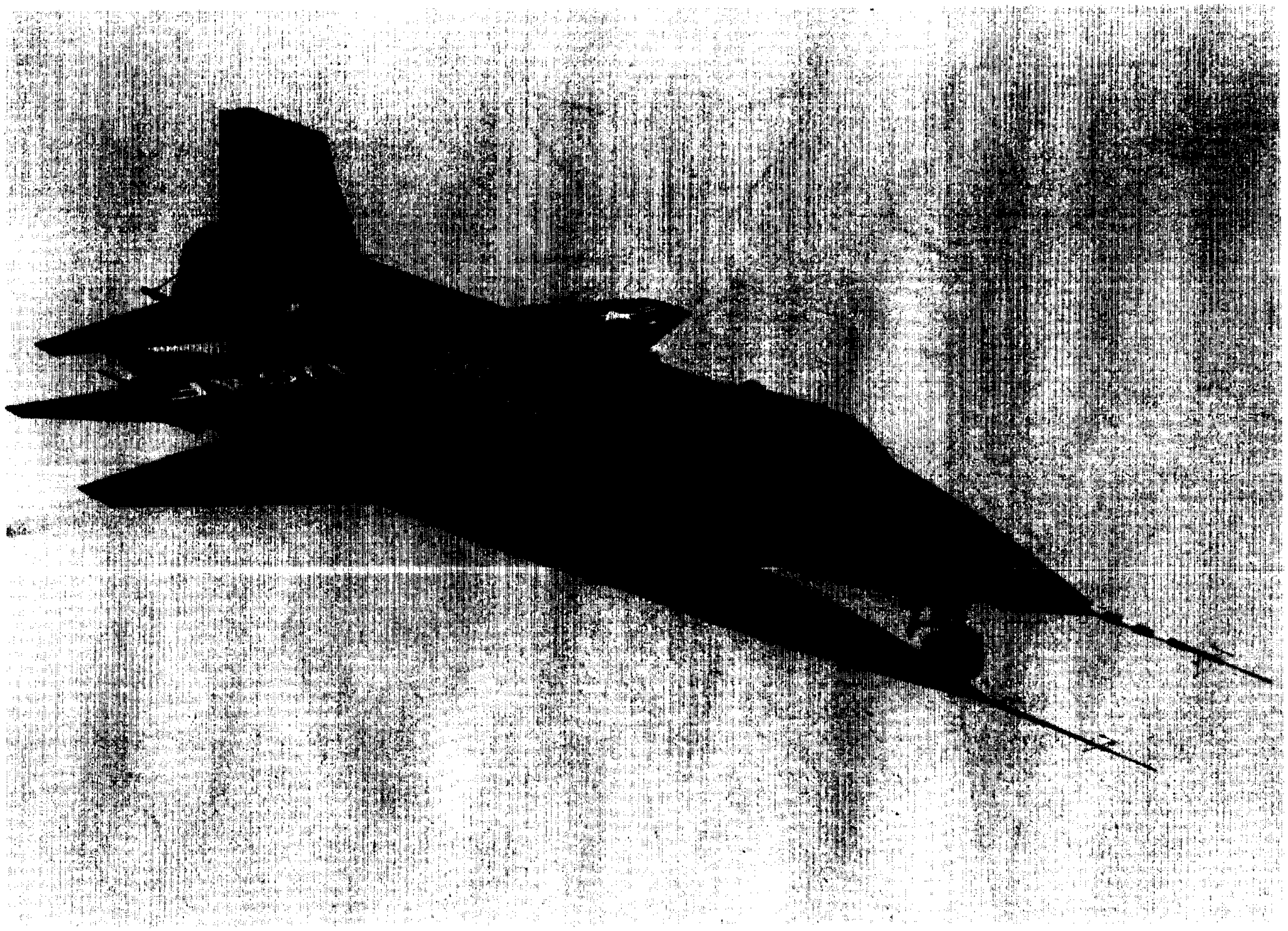
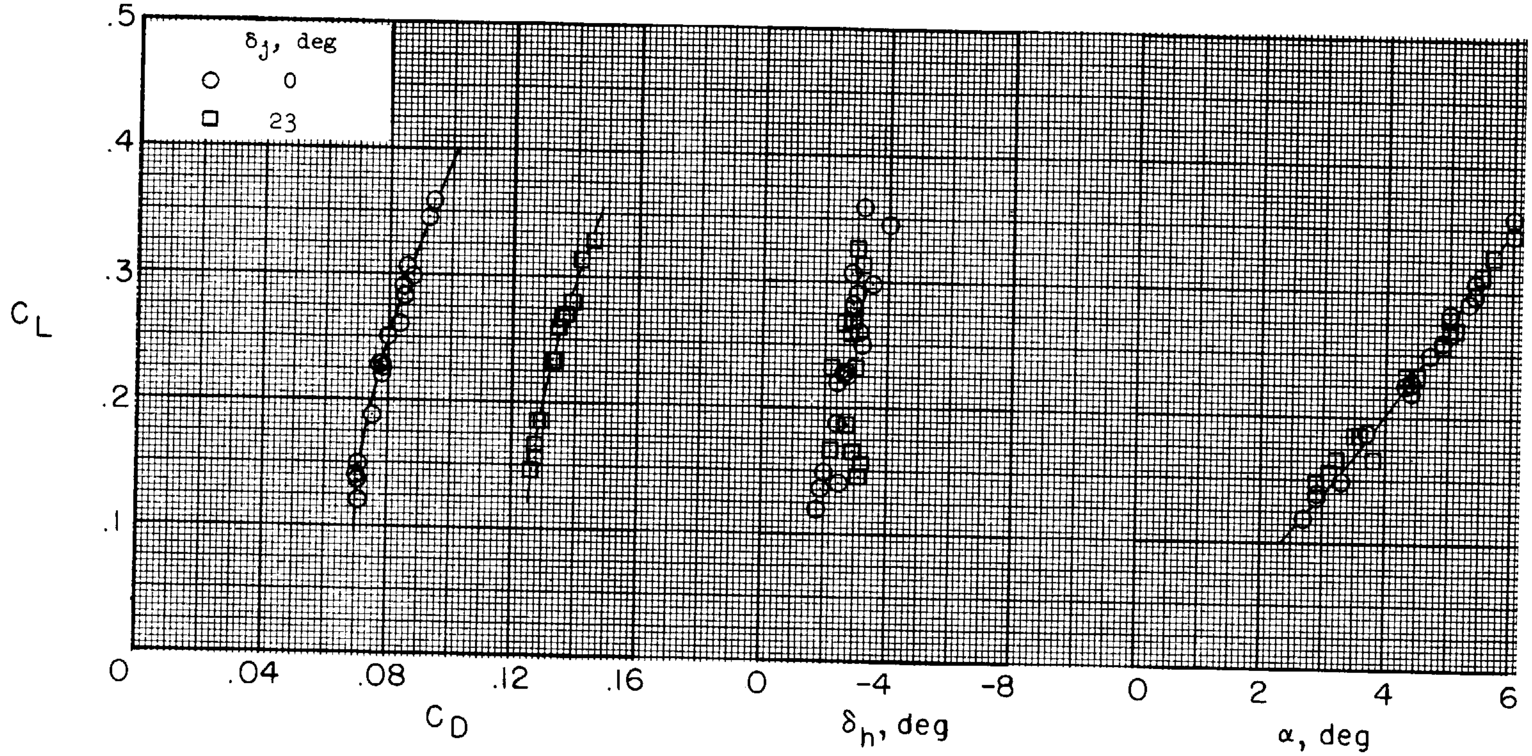
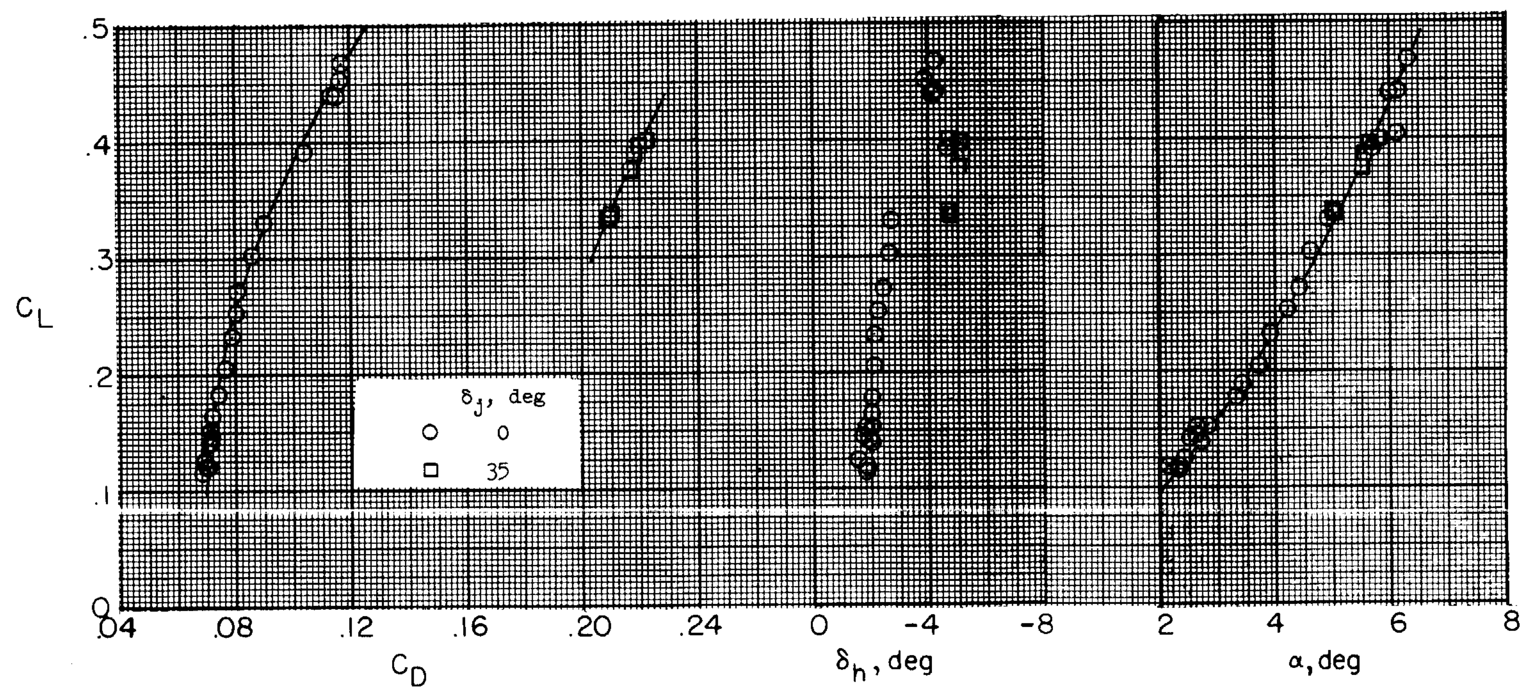


Figure 2.- Photograph of the X-15 airplane. E-5250



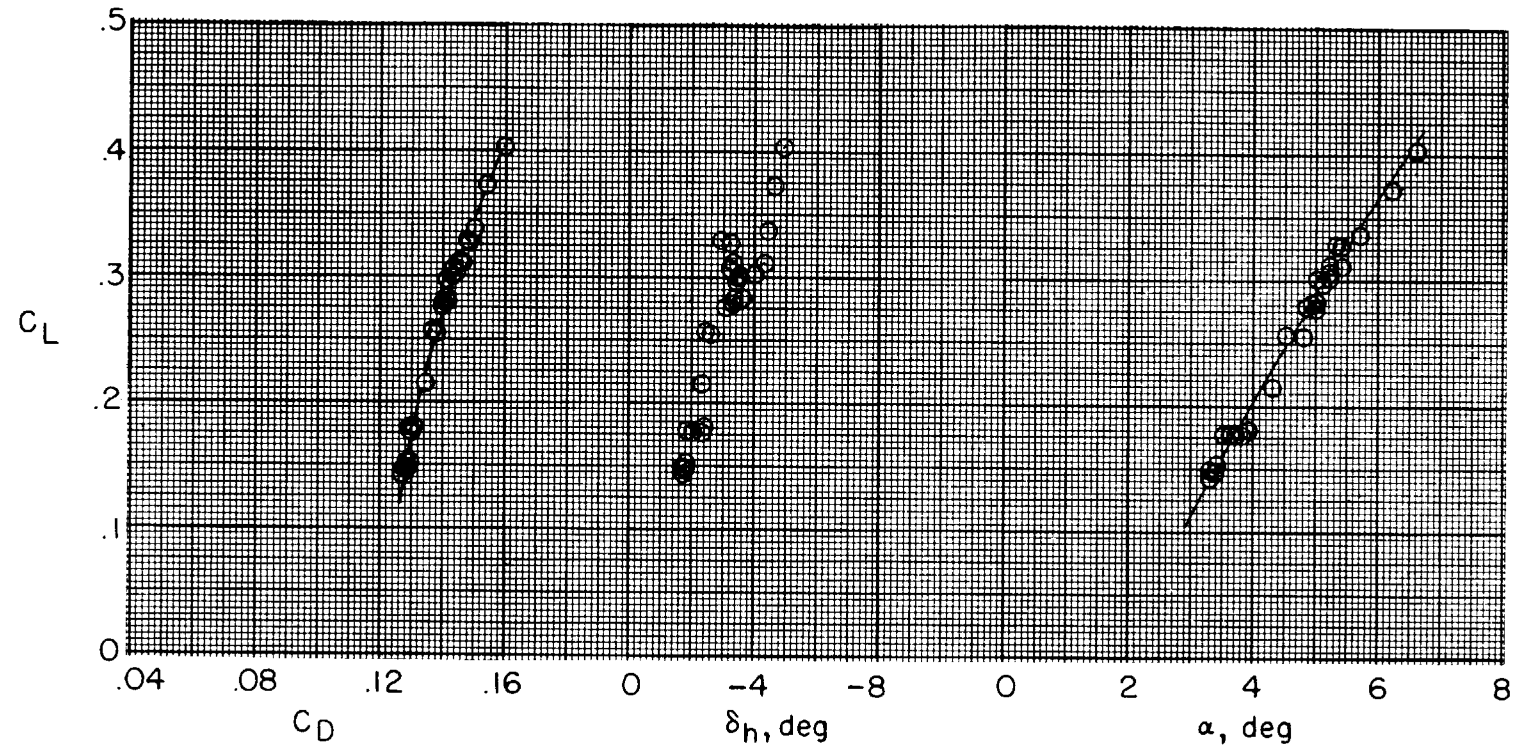
(a) $M \approx 0.7$, $R \approx 18.1 \times 10^6$ to 28.0×10^6.

Figure 3.- Variation of drag coefficient, horizontal-control deflection, and angle of attack with lift coefficient.



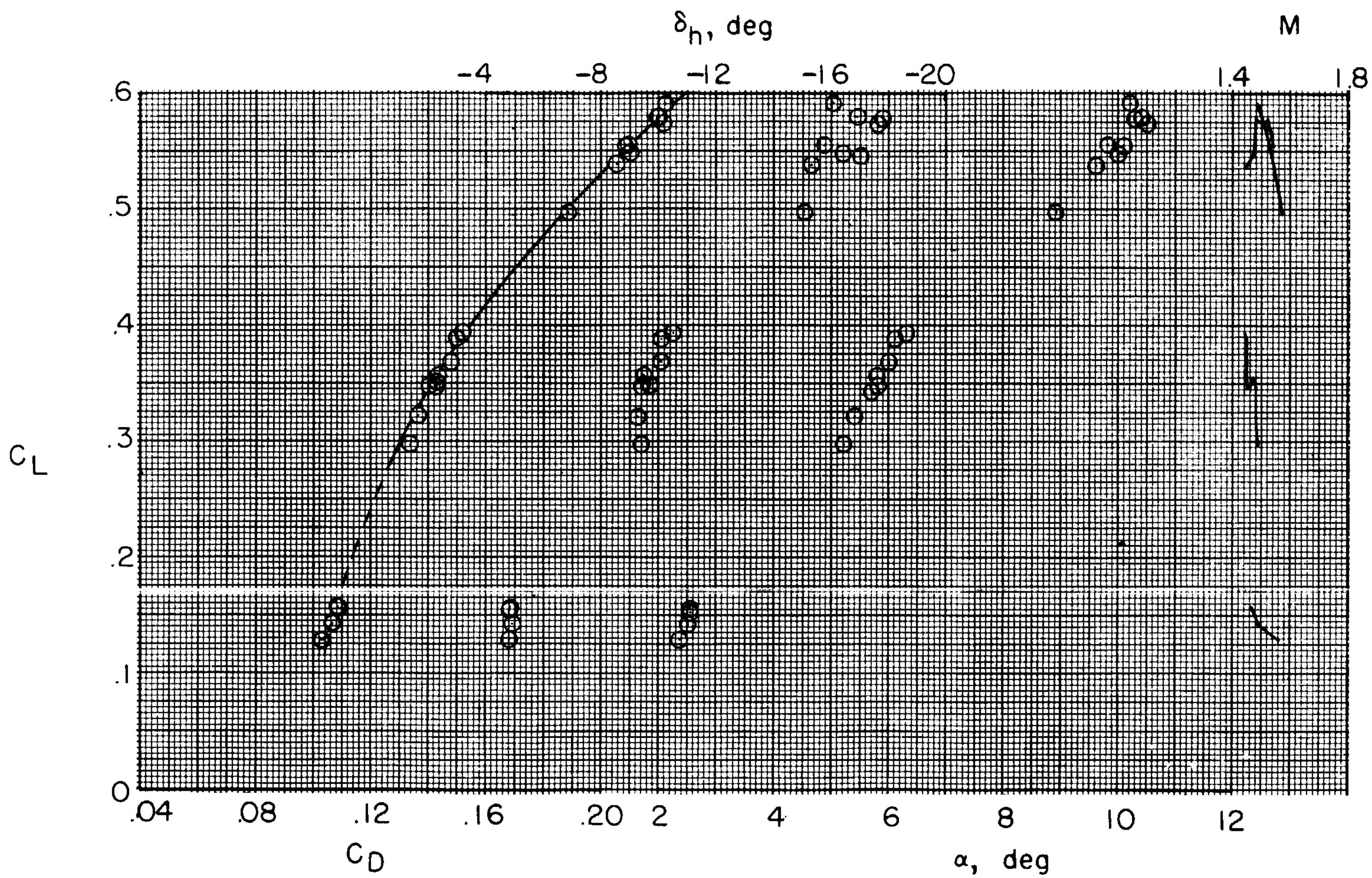
(b) $M \approx 0.9$, $R \approx 13.9 \times 10^6$ to 18.7×10^6.

Figure 3.- Continued.



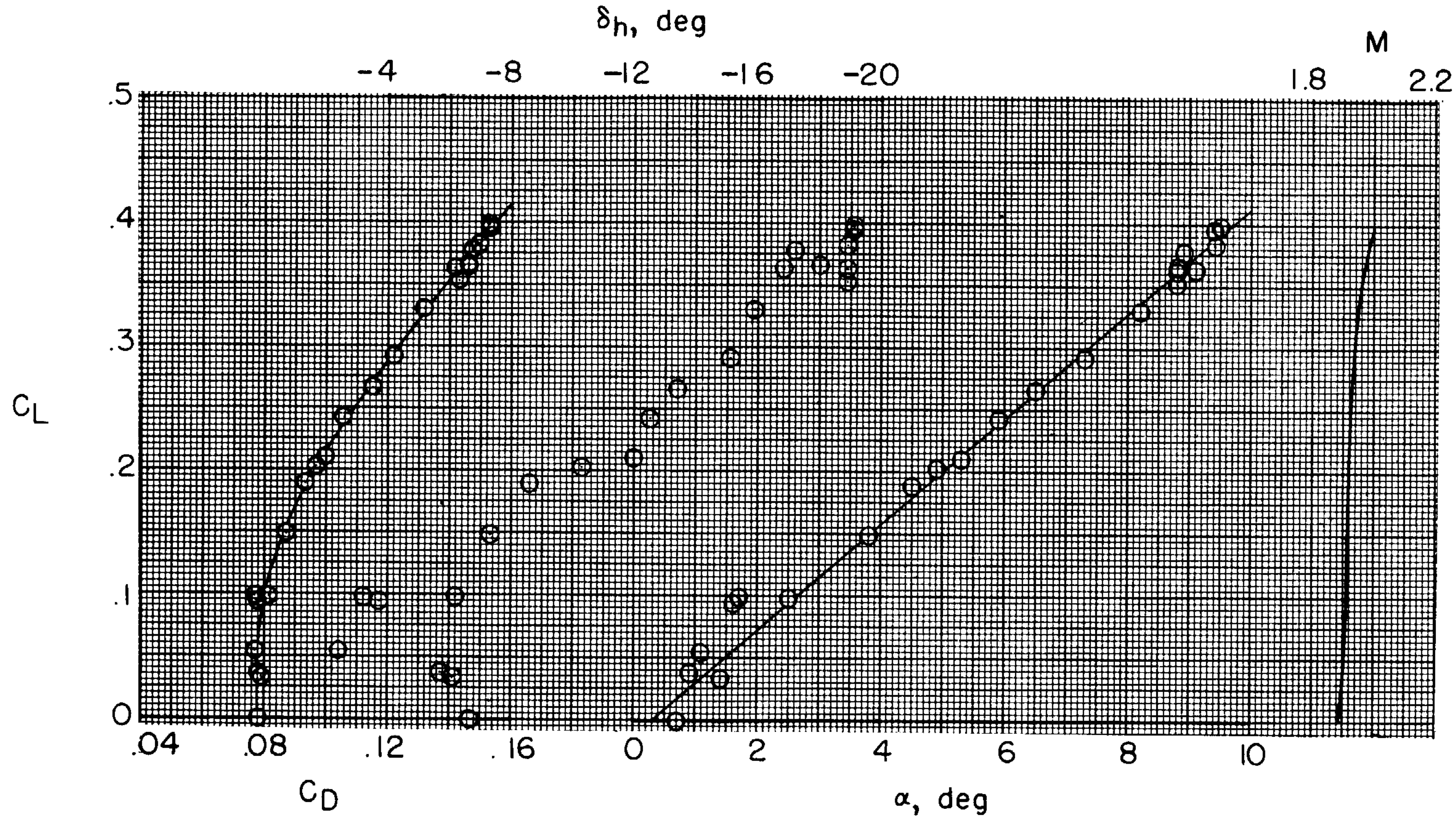
(c) $M \approx 1.1$, $R \approx 16.9 \times 10^6$.

Figure 3.- Continued.



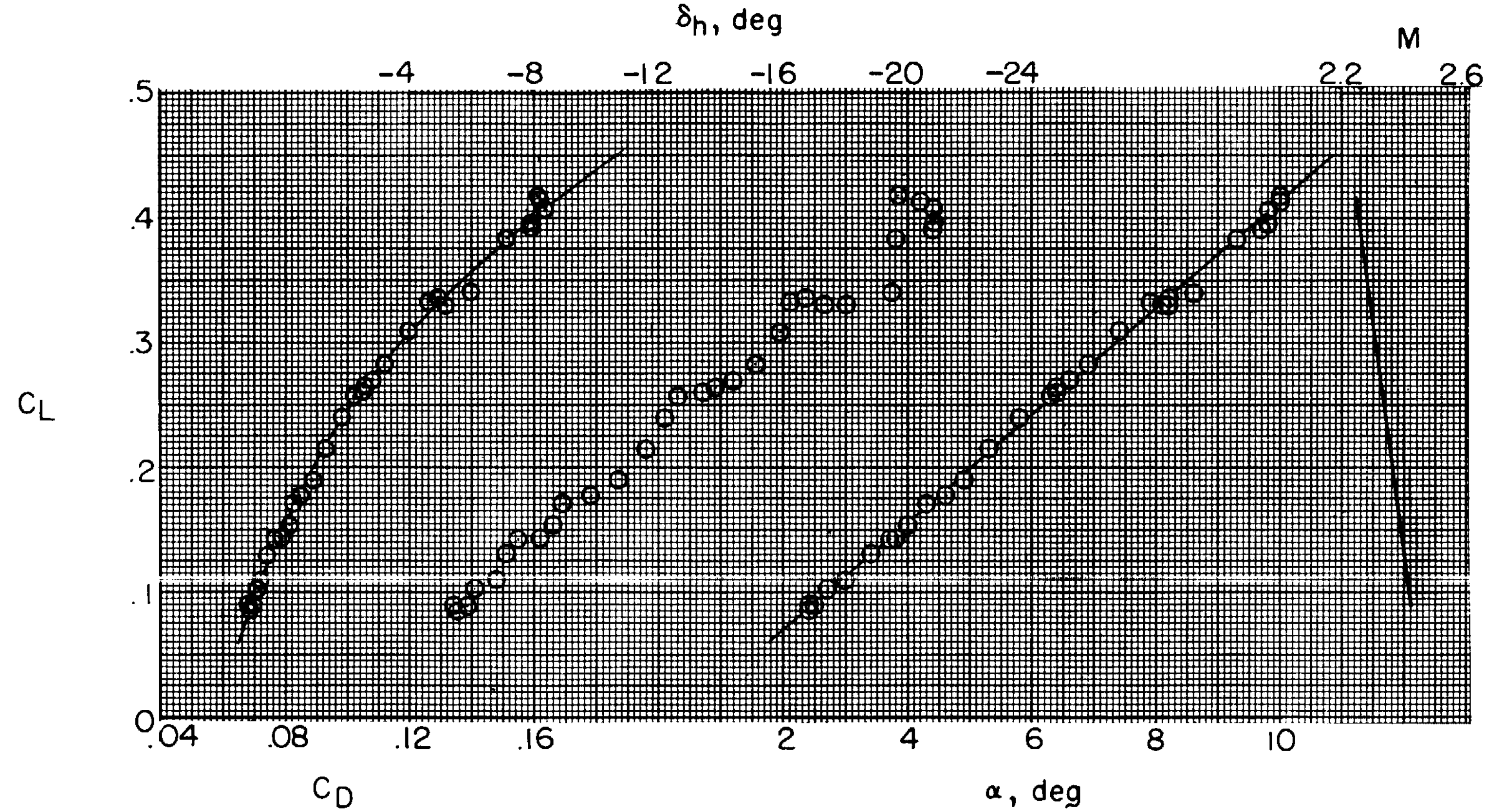
(d) $M \approx 1.5$, $R \approx 15.4 \times 10^6$ to 22.8×10^6.

Figure 3.- Continued.



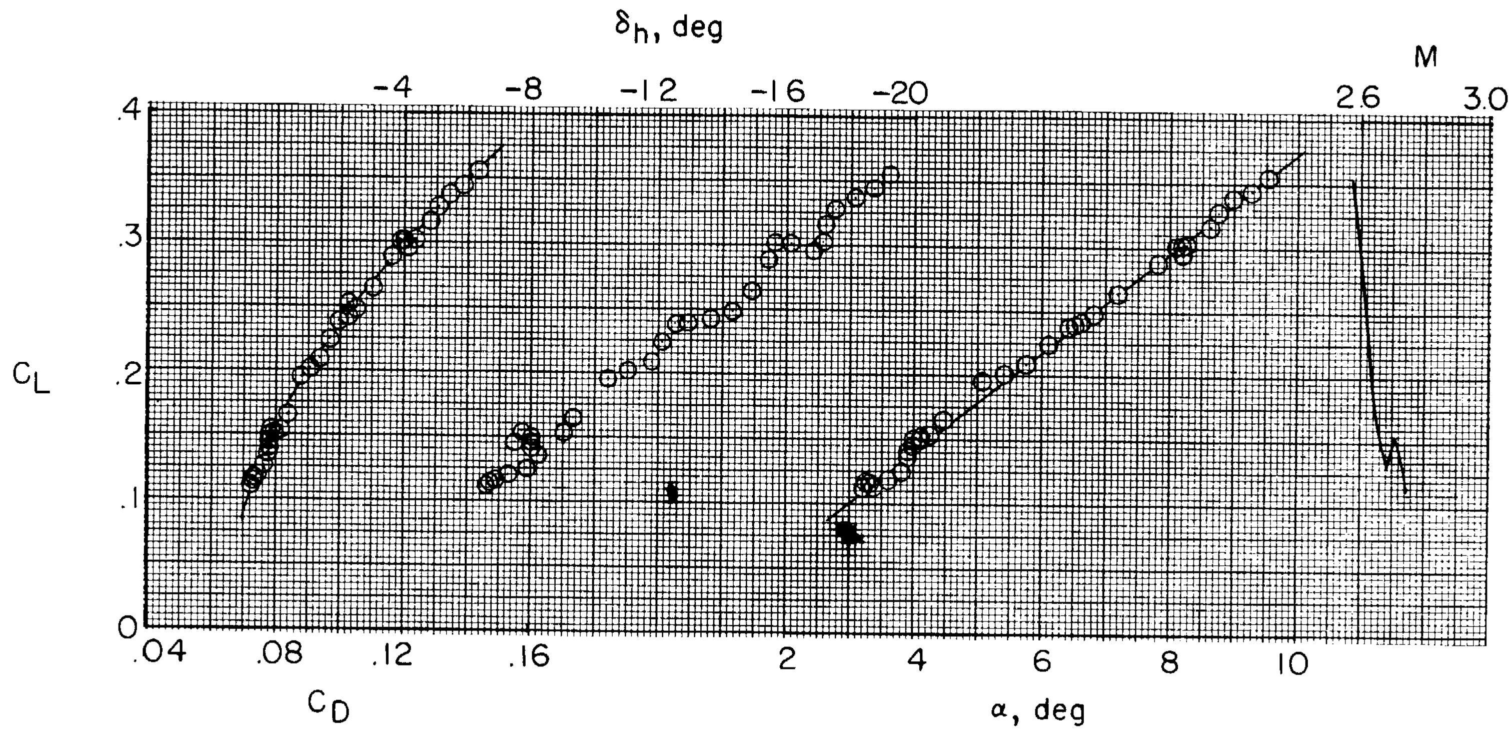
(e) $M \approx 1.9$, $R \approx 16.5 \times 10^6$.

Figure 3.- Continued.



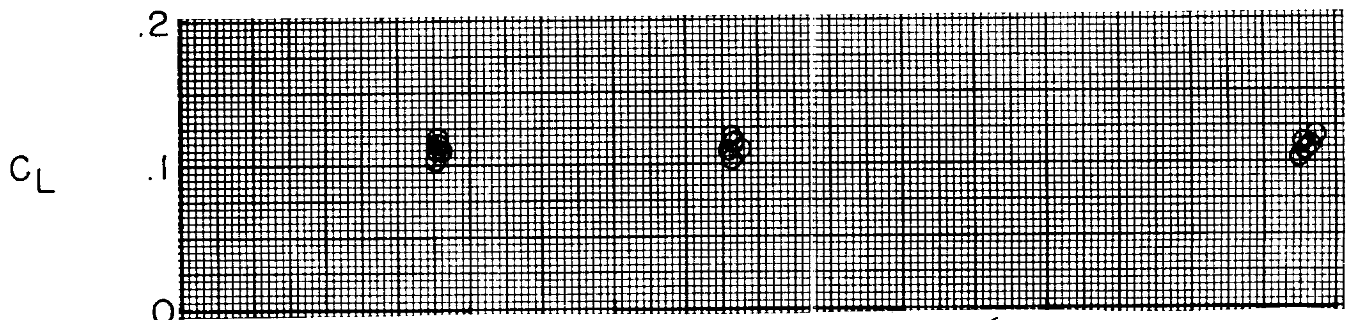
(f) $M \approx 2.3$, $R \approx 24.5 \times 10^6$.

Figure 3.- Continued.

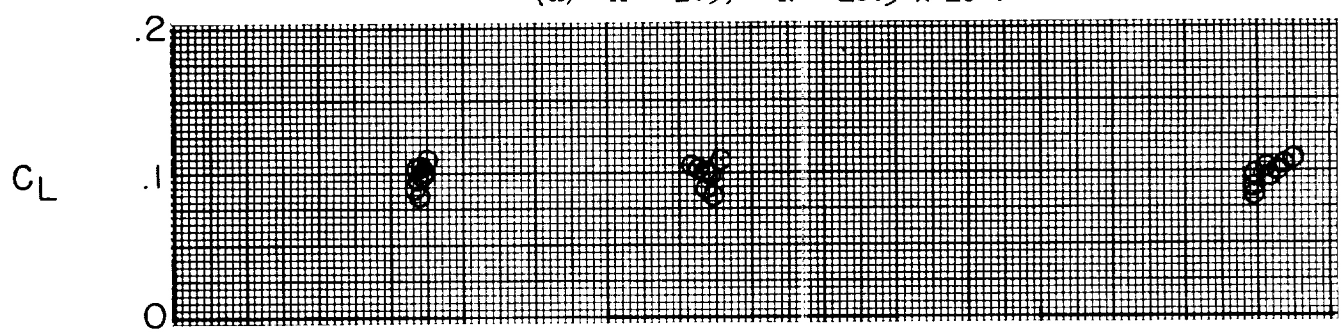


(g) $M \approx 2.7$, $R \approx 19.5 \times 10^6$.

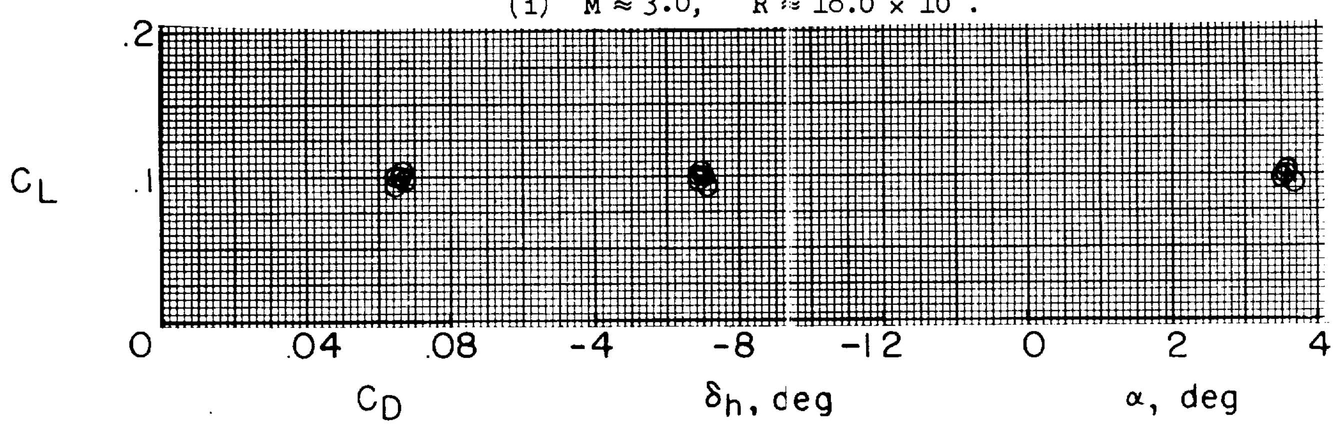
Figure 3.- Continued.



(h) $M \approx 2.9$, $R \approx 18.5 \times 10^6$.

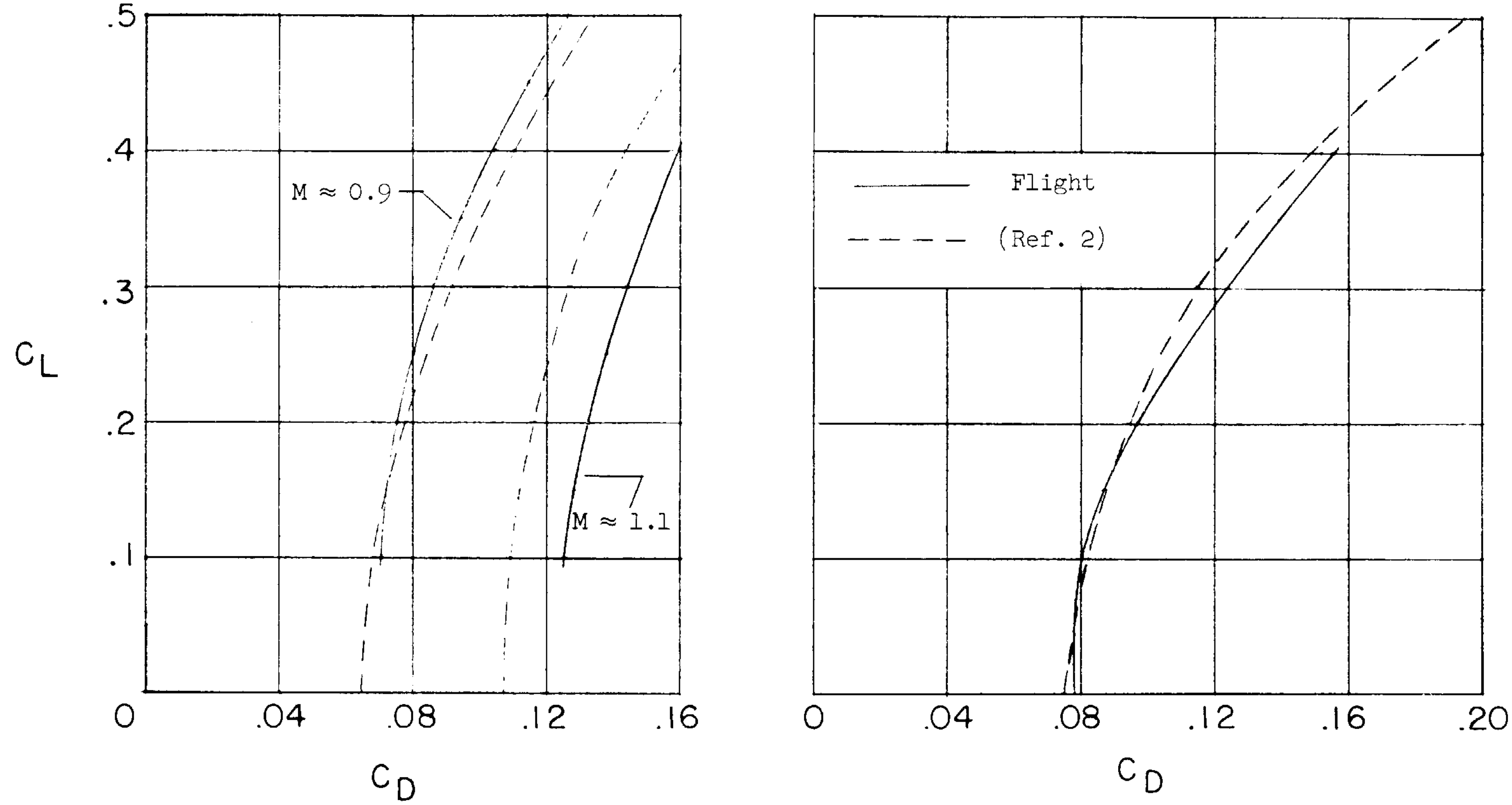


(i) $M \approx 3.0$, $R \approx 18.0 \times 10^6$.



(j) $M \approx 3.1$, $R \approx 17.0 \times 10^6$.

Figure 3.- Concluded.



(a) M ≈ 0.9 and 1.1.

(b) M ≈ 1.9 to 2.0.

Figure 4.- Comparison of representative flight-measured and estimated drag polars. Control-surface deflections at trim for estimated data and near trim for flight data.

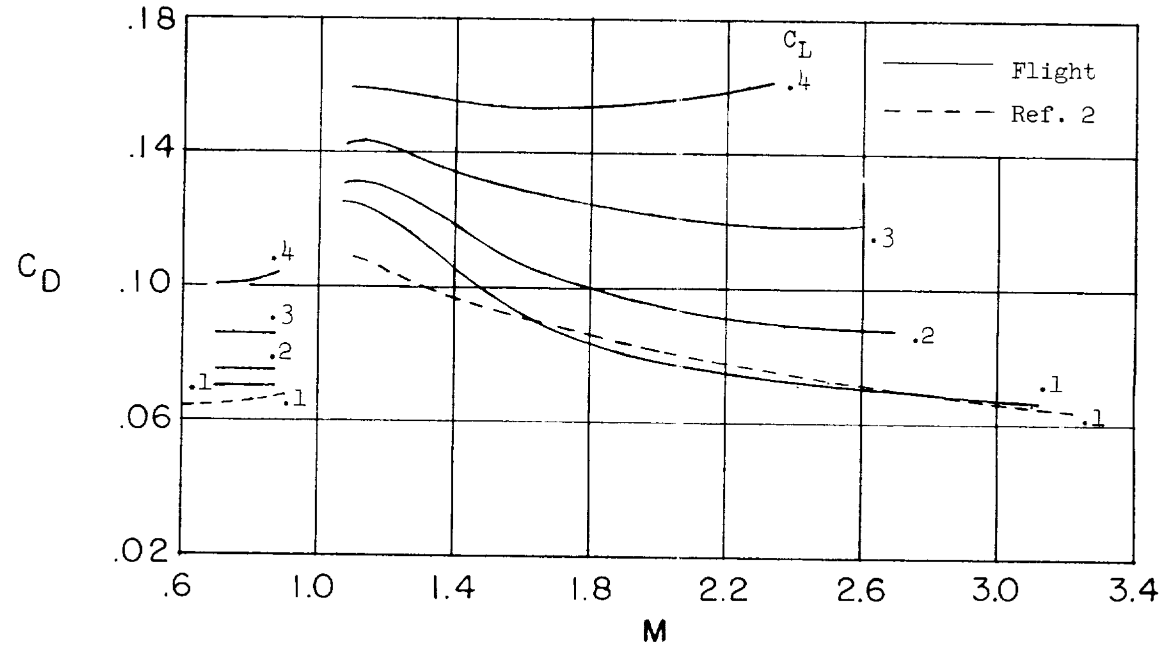


Figure 5.- Variation of drag coefficient with Mach number for several lift coefficients. Control-surface deflections at trim for data of reference 2 and near trim for flight data.

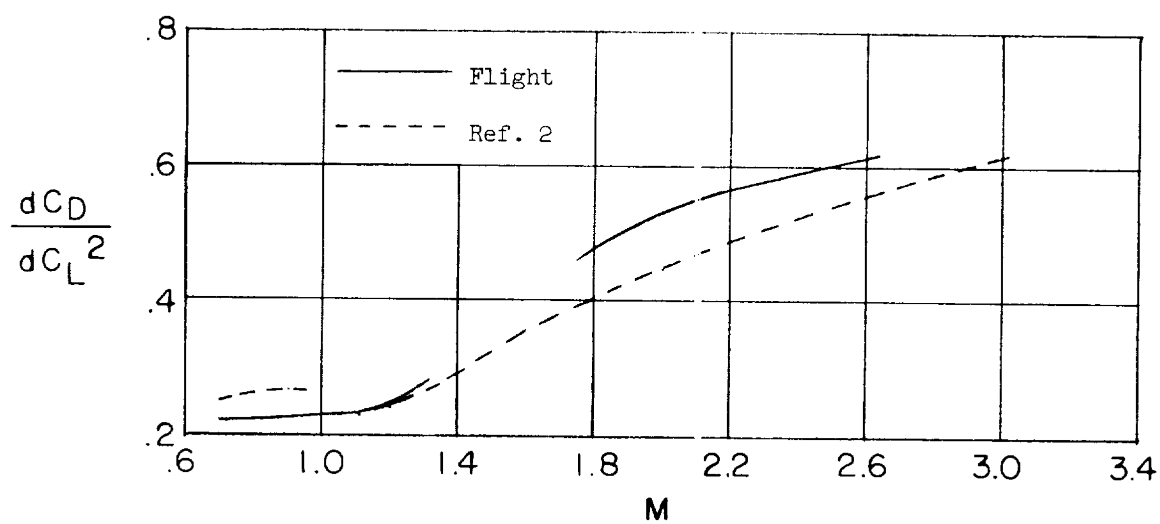


Figure 6.- Variation of drag-due-to-lift factor with Mach number. Control-surface deflections at trim for data of reference 2 and near trim for flight data. $C_L = 0.15$ to 0.35.

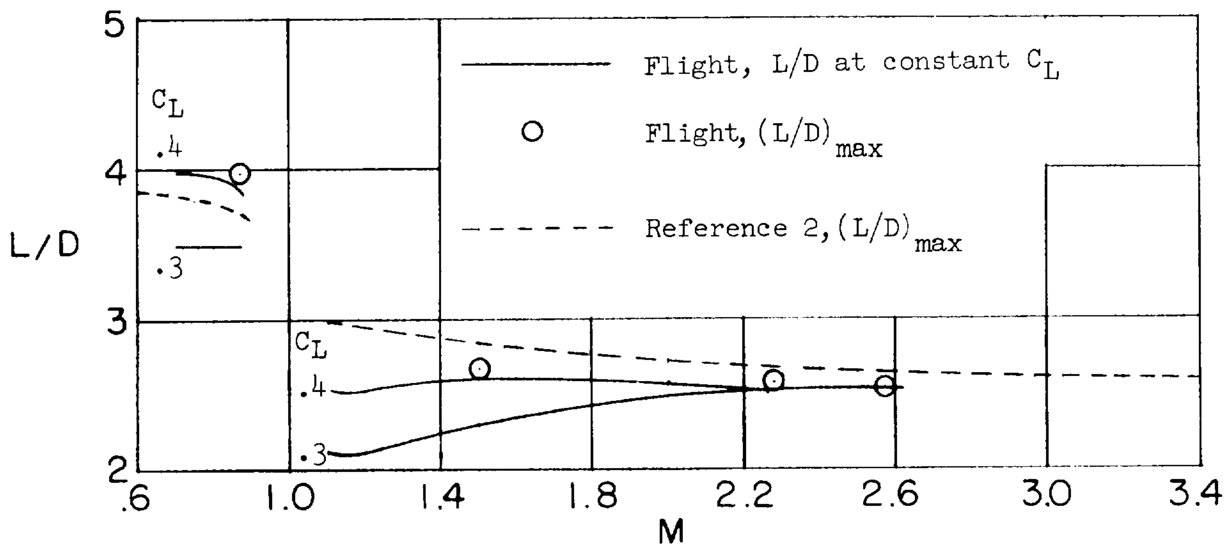


Figure 7.- Variation of lift-drag ratio with Mach number. Control-surface deflections at trim for data of reference 2 and near trim for flight data.